การพัฒนาโมบายแอปพลิเคชันกระดานสื่อความหมายการสื่อสารแบบเสริมและทางเลือกสำหรับเด็กสมองพิการที่มีความบกพร่องทางการสื่อสาร

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บทคัดย่อ

การวิจัยนี้ได้พัฒนาโมบายแอปพลิเคชันกระดานสื่อความหมายการสื่อสารแบบเสริมและทางเลือก (AAC) เพื่อสนับสนุนการสื่อสารของเด็กสมองพิการในโรงเรียนการศึกษาพิเศษแห่งหนึ่ง ในจังหวัดนนทบุรี ประเทศไทย โดยใช้กรอบแนวคิด HAAT Model (Human Activity Assistive Technology Model) ในการออกแบบ พร้อมผสมผสานองค์ประกอบมัลติมีเดีย เช่น ภาพ สัญลักษณ์ และเสียง เพื่อเพิ่มประสิทธิภาพการสื่อสารและความสะดวกในการใช้งาน การวิจัยมีผู้เข้าร่วม ได้แก่ เด็กสมองพิการจำนวน 10 คน และผู้เชี่ยวชาญจำนวน 4 คน เพื่อประเมินการใช้งานจริง โดยใช้เครื่องมือ QUEST (Quebec User Evaluation of Satisfaction with Assistive Technology) และ SUS (System Usability Scale) ร่วมกับการวิเคราะห์ประสิทธิภาพ แอปพลิเคชันได้รับความพึงพอใจในระดับ "ค่อนข้างพึงพอใจ" โดยมีคะแนน QUEST เฉลี่ย 4.18 สำหรับอุปกรณ์ และ 4.33 สำหรับบริการ ส่วนคะแนน SUS เฉลี่ย 80.5 ซึ่งสะท้อนถึงความเหมาะสมในการใช้งานระดับ "ดี" ผลการประเมินประสิทธิภาพพบว่าแอปพลิเคชันมีการใช้งาน CPU ต่ำ (3.56%) และการใช้พลังงานต่ำ (0.212 mAh) แต่การใช้หน่วยความจำ (255 MB) ซึ่งส่งผลกระทบต่ออุปกรณ์ที่มีทรัพยากรจำกัด เมื่อเปรียบเทียบกับกระดานสื่อสารแบบดั้งเดิม พบว่าแอปพลิเคชันมีความโดดเด่นในด้านความสะดวกในการพกพาและการปรับแต่ง ซึ่งสามารถตอบสนองความต้องการเฉพาะของผู้ใช้งานได้อย่างมีประสิทธิภาพมากยิ่งขึ้น การวิจัยนี้ชี้ให้เห็นถึงศักยภาพของเทคโนโลยี AAC ในการเพิ่มคุณภาพชีวิตและประสิทธิภาพการสื่อสาร พร้อมทั้งวางรากฐานสำหรับการพัฒนาในอนาคต เช่น การผสานเทคโนโลยีปัญญาประดิษฐ์ (AI) เพื่อขยายขอบเขตการใช้งานสำหรับกลุ่มเป้าหมายที่หลากหลายยิ่งขึ้น

คำสำคัญ: โมบายแอปพลิเคชัน กระดานสื่อความหมาย การสื่อสารแบบเสริมและทางเลือก (AAC) เด็กสมองพิการ เทคโนโลยีสิ่งอำนวยความสะดวก

Development of a Mobile Application for Augmentative and Alternative Communication (AAC) Board for Children with Cerebral Palsy and Communication Difficulties

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Abstract

This study aims to develop a mobile application based Augmentative and Alternative Communication (AAC) board to support the communication needs of children with cerebral palsy at a specialized school in Nonthaburi Province, Thailand. Guided by the Human Activity Assistive Technology (HAAT) Model, the application integrates multimedia elements including images, symbols, and audio to enhance communication efficiency and usability. Ten children with cerebral palsy and four experts participated in the study to evaluate real-world usability, using both the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) and the System Usability Scale (SUS), alongside performance metrics. The application achieved a “moderately satisfied” user satisfaction level, with QUEST scores averaging 4.18 (out of 5) for equipment and 4.33 (out of 5) for services, and an SUS score of 80.5 (out of 100), indicating “good” usability. Performance assessments demonstrated low CPU usage (3.56%) and minimal power consumption (0.212 mAh), although memory usage (255 MB) may pose challenges for low-resource devices. Compared to traditional communication boards, the application offers portability and adaptability enhancement to user needs. This study underscores the potential of AAC technology to improve communication and quality of life for users, establishing a foundation for the future integration of advanced features such as artificial intelligence to expand usability across broader populations.

Keywords: Mobile Application, Communication Board, Augmentative and Alternative Communication (AAC), Children with Cerebral Palsy, Assistive Technology

Background of the Study

Cerebral Palsy (CP) arises from abnormal brain development or damage (Patel et al., 2020) and is a leading cause of physical and intellectual disabilities in children, impairing motor control, balance, and communication (Paul et al., 2022; Pennington et al., 2020; Stadskleiv, 2020). Its prevalence is 1.5–4 per 1,000 live births worldwide, with similar rates in Thailand, where over 29,000 children are registered with CP, mainly in the northeastern region (Lang et al., 2012; National Centre on Birth Defect and Developmental Disabilities, 2022; National Statistical Office, 2017).

Because weak oral muscles and other physiological barriers often hinder speech (Mei et al., 2020), children with CP frequently experience frustration, emotional distress, and social isolation (Rudebeck, 2020). Enhancing communication skills is thus vital for improving their quality of life and social participation. Visual perception underpins early learning and cognitive development (Atkinson & Braddick, 2020). Drawing on Vygotsky's (2016) emphasis on symbols and gestures, studies indicate that visual symbols can stimulate cognitive abilities and bolster language comprehension in children with CP (Judge et al., 2020).

Assistive Technology (AT) helps children overcome physical and cognitive barriers. The Human Activity Assistive Technology (HAAT) model underscores the importance of designing AT to fit users' abilities, activities, and contexts (Cook & Polgar, 2014). While mobile AAC applications provide flexible communication solutions for children with CP, many originate abroad and face linguistic or cultural constraints (Moorcroft et al., 2019; Simakulthorn et al., 2023). Augmentative and Alternative Communication (AAC) systems, ranging from low-tech boards to high-tech mobile applications, employ symbols, letters, and colors to aid communication (Kristoffersson, 2020). They effectively support children with severe communication disorders (Avagyan et al., 2021), facilitating self-expression and social interaction (Norrie et al., 2021).

This study addresses these gaps by developing a culturally appropriate mobile AAC application for Thai children with CP, incorporating linguistic and cultural elements to enhance daily communication and social participation. Designed with visual symbols, voice synthesis, and an intuitive interface tailored to developmental needs, the tool aims to improve communication outcomes and overall quality of life for this population.

Purpose of the Study

This study aims to develop and evaluate a communication board that operates on a mobile application designed for children with cerebral palsy who face communication challenges. It seeks to provide a culturally appropriate and user-friendly solution tailored for the Thai context while assessing the app's usability, user satisfaction, and effectiveness compared to traditional communication boards. Ultimately, the goal is to enhance these children's independence, social inclusion, and overall quality of life.

Conceptual Framework

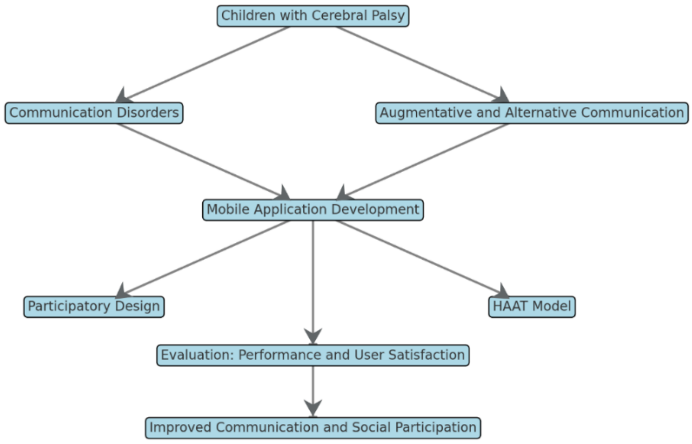

Figure 1 Conceptual Framework

This study's conceptual framework (Figure 1) addresses communication challenges in children with cerebral palsy by developing an Augmentative and Alternative Communication (AAC) based mobile application, guided by Participatory Design principles and the HAAT Model (Human Activity Assistive Technology). Emphasizing user abilities, activities, and contexts, the framework seeks to enhance communication and social participation through user input, technological feasibility, and iterative evaluation. It informs every stage of the research, from participant selection and application development to measurement tool selection and data analysis.

First, the Participants subsection describes recruitment criteria and demographics. Next, the Development Process of the AAC Board explains the systematic, user centered approach aligned with the HAAT Model and participatory design. In the Research Measurement and Developing Measurement Tools section, two standardized instruments, the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0) and the System Usability Scale (SUS), are used to evaluate user satisfaction and usability. Subsequently, the Application Effectiveness Evaluation (Performance Testing) examines technical performance under real world conditions, reflecting the framework's focus on usability and feasibility. The Data Collection Process then details how both quantitative and qualitative data were gathered to capture insights on communication outcomes. Finally, the Data Analysis section outlines the statistical and interpretive methods used to assess the application's impact on communication and social participation for children with cerebral palsy.

Participants

The study was conducted at a special education school in Nonthaburi Province, Thailand, which serves about 260 children with cerebral palsy aged 3 to 18, supported by 40 teachers and a speech language pathologist. A purposive sampling method was employed

(Thomas, 2022) to select participants whose specific characteristics would yield rich and relevant data. Ten children with mild to moderate cerebral palsy (GMFCS Levels I and II), aged 6 to 17, and with sufficient fine motor skills for tablet or computer use were recruited. None had cognitive deficits that would interfere with participation, and all had at least one year of experience with Augmentative and Alternative Communication (AAC) tools. Because they were under 18, each child received an age-appropriate explanation of the study and provided assent, while written consent was obtained from parents or legal guardians. Three teachers, each with at least three years of experience working with children with cerebral palsy, and one speech language pathologist with over three years of professional experience also participated. Their expertise in communication aids such as communication boards and picture books was key to implementing the mobile application in the educational setting and evaluating its effectiveness in improving communication skills.

The development process of the mobile application for the Augmentative and Alternative Communication (AAC) board

The development process of the mobile application for the Augmentative and Alternative Communication (AAC) board followed a structured, iterative approach guided by user centered design principles to address the communication needs of children with cerebral palsy. It began with a needs assessment involving teachers, caregivers, and a speech language pathologist at a specialized school in Nonthaburi Province, Thailand, identifying challenges such as limited motor skills and impaired speech. In response, the user interface and features were centered on accessibility and simplicity, integrating SymbolStix symbols for visual support and Botnoi Voice AI for synthesized voice output. The interface accommodated minimal fine motor skills, employing large buttons, real time feedback, and customizable symbol categories and voice settings. Using Android Studio to ensure device compatibility, the development team conducted iterative testing and prototyping with teachers and the speech language pathologist to refine navigation, symbol selection, and voice clarity. After finalizing the application, it was installed on tablets and training sessions were held to help teachers and caregivers confidently support the children. Informed by the Human Activity Assistive Technology (HAAT) model, the resulting tool was functional, user friendly, and adaptable, empowering children with cerebral palsy to express their needs, thereby enhancing their quality of life and social inclusion.

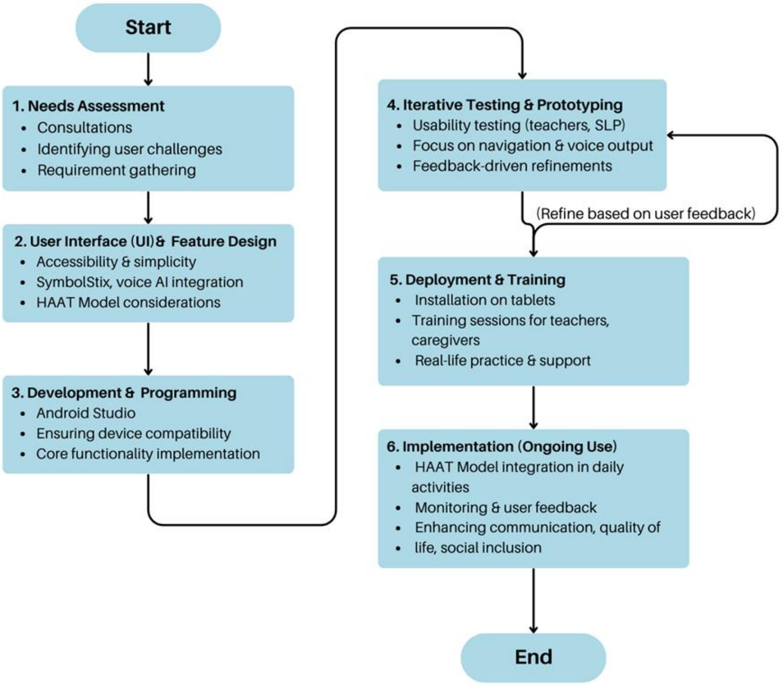

Figure 2 Development Process Flow Diagram for the Mobile AAC Application

Research Measurement and Developing Measurement Tools

This study employed various validated quantitative and qualitative instruments, including the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0) and the System Usability Scale (SUS), to assess the mobile application's functionality and user satisfaction among children with cerebral palsy who have communication difficulties. In addition, interviews with teachers and a speech language pathologist enriched the quantitative findings.

Some young children, especially those with severe communication difficulties, could not complete certain questionnaire items independently. A speech language pathologist (SLP) facilitated communication by observing nonverbal cues, simplifying language, and using symbol boards or picture cues. When verbal responses were not possible, the SLP interpreted expressions, gestures, or vocalizations. If children still could not convey responses, proxy input from caregivers or teachers, in consultation with the SLP, helped validate or clarify reactions. This combination of direct observation, facilitated communication, and proxy reporting upheld ethical standards and yielded meaningful satisfaction data reflecting each child's true experience with the assistive technology.

Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0)

The QUEST 2.0 was used to assess participant satisfaction with the assistive technology in two core dimensions: satisfaction with the device (Size, Weight, Ease of adjustment, Safety, Durability, Ease of Use, Comfort, Effectiveness) and satisfaction with related services (Service

Delivery, Repair and Maintenance, Professional Services, Follow Up). Each item is rated on a 5-point Likert scale from 1 ("not satisfied at all") to 5 ("very satisfied"). Chosen for its reliability and effectiveness in measuring user satisfaction with assistive technologies, particularly among children with disabilities, the QUEST 2.0 is widely used in similar contexts (Demers et al, 2002). In this study, it was adapted to the Thai context following Panyawong's (2017) validated Thai version.

System Usability Scale (SUS)

The SUS was used to measure the application's usability and is widely recognized in human computer interaction, proven effective for evaluating system usability (Brooke, 1996). It consists of 10 items rated on a 5-point Likert scale from strongly disagree to strongly agree, offering a quick and reliable assessment of user interactions. The final scores indicate how users perceive ease of use and overall functionality, making the SUS ideal for evaluating this augmentative and alternative communication tool.

Application Effectiveness Evaluation (Performance Testing)

The performance evaluation assessed the application's effectiveness, reliability, and scalability for children with cerebral palsy. Key metrics included response time (expected completion within 2 seconds), throughput (over 100 requests per second under normal conditions), CPU utilization (within 70 to 80 percent), and memory usage (not exceeding 200 MB). An error rate below 1 percent ensured accurate communication, while scalability testing confirmed the system could accommodate up to five times the current user base with no more than a 10 percent performance reduction. These evaluations validated that the application meets high performance standards, providing a reliable and efficient tool for its users.

Data Collection Process

Data collection spanned 12 weeks, using a structured approach to gather both quantitative and qualitative insights. In the first week, baseline data were collected, including QUEST 2.0 evaluations, consent forms, and personal information, establishing a pre-intervention benchmark. In week five, the mobile application communication board was introduced to children, teachers, and the speech language pathologist, accompanied by training sessions for hands on experience. During this phase, the System Usability Scale (SUS) was administered for initial feedback on usability. From weeks six to nine, participants integrated the application into daily routines while receiving weekly support to address technical issues, enabling continuous data collection on usability and effectiveness. In weeks ten and eleven, post intervention evaluations repeated QUEST 2.0 and SUS, supplemented by semi structured interviews with teachers and the speech language pathologist for deeper insights into user experiences and improvements in communication abilities. By week twelve, both pre and post intervention datasets were compiled for analysis, ensuring comprehensive and reliable data on the application's effectiveness.

Data Analysis

Quantitative and qualitative methods were used to assess the mobile application's impact on user satisfaction and communication outcomes. Descriptive statistics, including means and standard deviations, were calculated for each item on the QUEST 2.0 and the System Usability Scale (SUS), providing an overview of satisfaction and usability before and after the intervention. SUS scores (Ranging from 0 to 100) indicated overall usability, with scores above 68 representing above average usability and scores below 50 suggesting room for improvement. To evaluate changes in user satisfaction, a Wilcoxon Signed Rank Test was conducted on the pre and post intervention QUEST 2.0 scores, a nonparametric approach suitable for small samples and ordinal data. Individual SUS item scores highlighted specific strengths and potential areas of improvement, while aggregated scores offered a broader measure of usability. These analyses demonstrated the application's effectiveness in enhancing user satisfaction and communication abilities and supported evidence-based conclusions regarding its potential for broader implementation.

Results

1. **The AAC mobile application developed in this study**

Figure 3 Homepage

Homepage

The homepage (Figure 3) presents a simple interface with large buttons and child friendly illustrations, accommodating varied motor and cognitive abilities. It guides users to the main communication board.

Figure 4 User’s gender Selection Page

User's Gender Selection Page

Figure 4 shows the avatar selection screen, increasing engagement through personalized choices. Users can also select a voice matching their chosen avatar, enhancing familiarity and encouraging enthusiastic interaction.

Figure 5 Communication Board Page

Communication Board Page

Figure 5 illustrates the core board with common words and actions. Teachers and a speech language pathologist reported intuitive icons and layout, enabling basic sentence formation. The application offers 10 pages and 240 vocabulary items, covering diverse communication scenarios and supporting language needs for children with cerebral palsy.

Figure 6 Bottom Setting Page

Bottom Setting Page

Figure 6 displays the bottom navigation bar and settings interface, allowing quick parameter adjustments without leaving the communication board. Users can also resize buttons and text for different motor and visual needs.

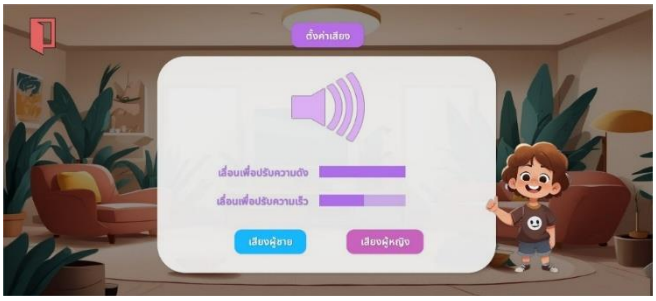

Figure 7 Audio Setting Page

Audio Setting Page

Figure 7 provides volume and speech output speed controls, benefiting children with varying auditory sensitivities by permitting individualized sound adjustments.

Figure 8 Vocabulary Customization Page

Vocabulary Customization Page

Figure 8 demonstrates how caregivers and therapists can add or remove vocabulary items, maintaining flexibility as children expand their language use.

Figure 9 Communication Board in Use

Communication Board in Use

Figure 9 illustrates the communication board in an active session, where users select from multiple categories of symbols to express needs, emotions, and ideas. Large, clearly labeled buttons accommodate varying motor abilities, while a Play Voice feature provides audio output for selected items. This real time feedback helps children with cerebral palsy articulate messages more independently and promotes social interaction.

2. Performance Evaluation of the Mobile Application Communication Board

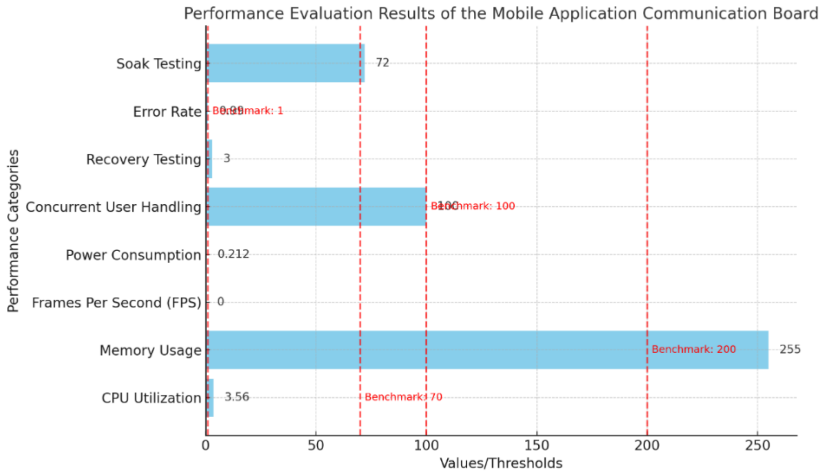

Figure 10 Performance Evaluation Results of the Mobile Application Communication Board

The performance evaluation of the mobile application communication board demonstrates its efficiency and reliability across key metrics. The application achieved low CPU utilization (3.56%), well below the 70% benchmark, ensuring smooth operation. Memory usage, at 255 MB, slightly exceeded the 200 MB benchmark, suggesting potential for optimization on devices with limited resources. Graphical performance was flawless, with no slow frames or stuttering, ensuring a seamless user experience. Power consumption was highly efficient at 0.212 mAh, minimizing battery impact. The system supported up to 100 concurrent users with an average response time of 2 seconds, maintaining performance even under increased load. Recovery testing showed the system could recover from crashes within 3 minutes without data loss, while the error rate remained under 1%, reflecting accuracy and consistency. Soak testing over 72 hours confirmed stability with no memory leaks and sustained response times.

Overall, the application is effective and reliable, meeting or exceeding benchmarks, with room for memory optimization to enhance performance further. It is a robust tool for supporting communication needs in children with cerebral palsy.

3. Communication Difficulties Among Participants

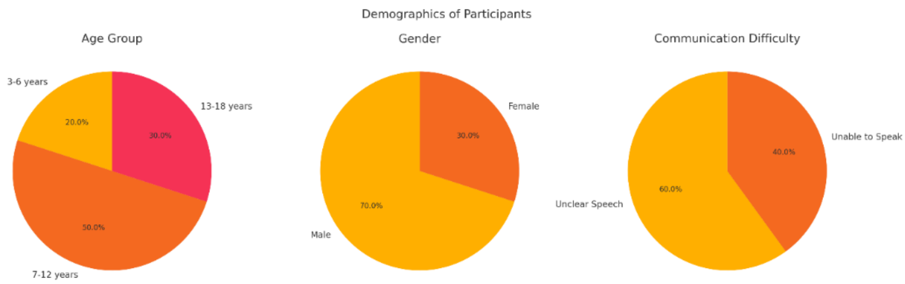

Figure 11 Demographic Overview and Communication Difficulties of Participants

The study found that all participants experienced significant communication difficulties prior to the intervention, with challenges including unclear speech (46.15%) and complete inability to speak (38.46%). After utilizing the mobile AAC application, qualitative feedback indicated noticeable improvements in communication efficiency and confidence. Teachers and caregivers reported enhanced clarity in expressing needs and emotions, demonstrating the application's potential to address core communication barriers effectively.

4. QUEST 2.0 scores: Pre- and Post-Intervention

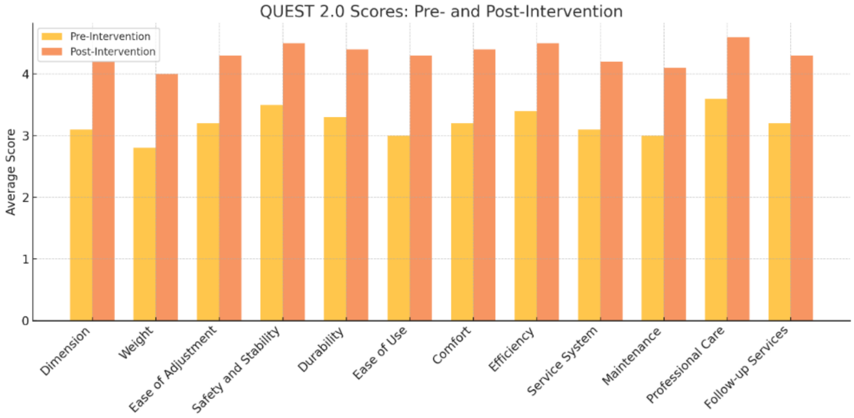

Figure 12 QUEST 2.0 scores: Pre- and Post-Intervention Comparison

The results of the QUEST 2.0 evaluation, conducted both before and after the intervention, reveal significant improvements in participant satisfaction with the assistive technology. The evaluation encompassed two domains: device-related satisfaction and service-related satisfaction. In the device-related domain, the pre-intervention mean score was 3.28 (SD = 1.00), indicating moderate satisfaction. Post-intervention, the mean score increased significantly to 4.18 (SD = 0.58), reflecting marked improvements in the communication board's design, usability, and functionality. Similarly, in the service-related domain, the pre-intervention mean score was 3.40 (SD = 1.03), indicating a somewhat positive experience with service delivery. This score increased to 4.33 (SD = 0.33) post-intervention, underscoring enhancements in professional care, maintenance, and follow-up services linked to the mobile application.

Overall, the total QUEST 2.0 mean score rose from 3.31 (SD = 1.46) pre-intervention to 4.26 (SD = 0.11) post-intervention, indicating a statistically significant increase in satisfaction with both the assistive device and associated services. These findings highlight the effectiveness of the developed mobile application in addressing the needs of children with cerebral palsy and their caregivers. The intervention demonstrates the potential of customized mobile applications to improve communication outcomes and user satisfaction with assistive technology.

The graph in Figure 12, visually illustrates the average scores from the QUEST 2.0 assessment across pre- and post-intervention phases. The x-axis represents the evaluated attributes, including dimension, weight, ease of adjustment, safety and stability, durability, ease of use, comfort, efficiency, and service-related factors like service system, maintenance, professional care, and follow-up services. The y-axis reflects average scores on a Likert scale from 1 (highly dissatisfied) to 5 (Highly Satisfied). Post-intervention scores (Orange Bars) show substantial improvements across all attributes compared to pre-intervention scores (Yellow Bars). Noticeable enhancements in weight, ease of adjustment, and maintenance demonstrate the intervention's impact on both device usability and service delivery.

5. System Usability Scale (SUS) Scores

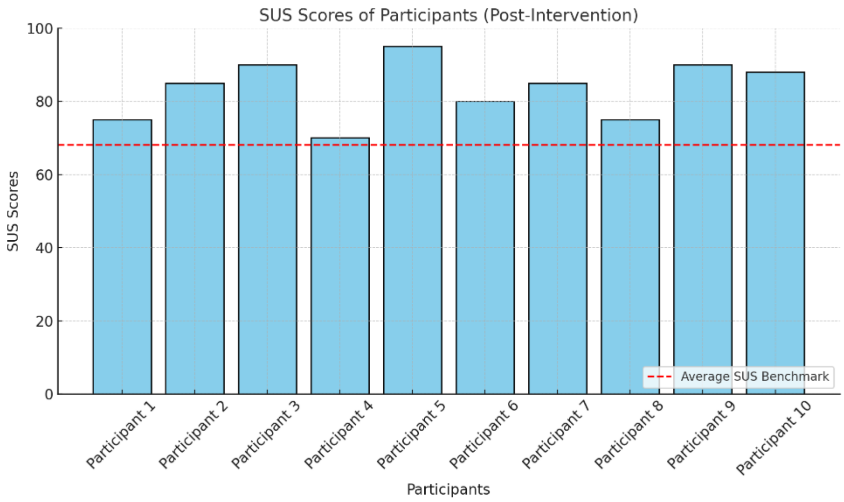

Figure 13 QUEST 2.0 scores Pre and Post-Intervention Comparison

The System Usability Scale (SUS) scores, as depicted in Figure 13, evaluate participants' perceptions of the usability of the mobile application communication board. The average SUS score across all participants was 80.5, which is significantly higher than the industry benchmark of 68, indicating excellent usability. Individual participant scores ranged from 70 to 90, with all participants surpassing the benchmark, demonstrating the application's effectiveness in terms of ease of use, intuitive design, and reliability. These results suggest that the mobile application effectively addressed the usability needs of children with cerebral palsy, ensuring smooth navigation and accessibility. Figure 13 illustrates the SUS scores for each participant, with the red dashed line representing the average SUS benchmark. The consistently high scores reinforce the application's success in achieving its usability objectives and supporting effective communication for users.

Discussion

This study aimed to develop and evaluate a mobile application communication board for children with cerebral palsy who face communication challenges. The results demonstrated the application’s ability to address specific user needs, achieve technical efficiency, and improve user satisfaction.

Addressing Specific User Needs

The mobile application was designed to accommodate the unique communication limitations of children with cerebral palsy by employing clear symbols, a simple user interface, and culturally relevant content, which included vocabulary items, symbols, and imagery reflective of the local language, daily activities, and societal norms. The findings align with studies by Light et al. (2007) and Kleinert (2020) which emphasize the importance of straightforward, user-friendly designs in AAC tools to enhance social interaction and communication. Moreover, the use of culturally resonant language and visuals, as suggested by Lorah et al. (2022), significantly reduced communication barriers, contributing to the high levels of user satisfaction observed in this study. The application's ability to enhance communication and social participation was evident as children used it to express basic needs and communicate confidently. This supports Syriopoulou-Delli and Eleni (2022), who found that AAC tools increase classroom participation and improve social skills in children with cerebral palsy. Additionally, the integration of context-specific features aligns with findings by Norrie et al. (2021) which highlighted the importance of incorporating cultural context into AAC system design.

Enhancing Mobile Application Functionality

The participatory design approach adopted in this study ensured that the application met real-world needs. This aligns with Babic et al. (2015), who highlighted the importance of involving users throughout the development process to improve functionality and relevance. Guided by the Human Activity Assistive Technology (HAAT) model (Cook & Polgar, 2014), the application achieved a high usability score of 80.5 on the System Usability Scale, reflecting its effectiveness in facilitating communication and social interaction. The iterative development process allowed users and stakeholders to provide feedback at various stages, ensuring the application's features were tailored to their needs. This approach is consistent with Kleinert (2020), who emphasized the importance of user-centered designs for AAC tools.

Technical Efficiency of the Application

The performance evaluation revealed the application's efficiency in key technical aspects, including low CPU usage (3.56%), minimal power consumption (0.212 mAh), and fast response times (2 seconds). These findings align with Kaya et al. (2019), who reported that resource-efficient applications enhance user experiences. The application's scalability, demonstrated by its ability to support up to 100 concurrent users with minimal performance degradation, highlights its potential for broader adoption. However, the memory usage exceeded the benchmark of 200 MB, reaching 255 MB, which could impact performance on devices with limited resources. Addressing this limitation, as recommended by Demers et al. (2002), could further improve device compatibility and user experience.

User Satisfaction

The QUEST 2.0 and SUS scores indicated high levels of user satisfaction, particularly in terms of ease of use and responsiveness. Post-intervention, the mean satisfaction score for device-related attributes increased from 3.28 to 4.18, while service-related satisfaction rose from 3.40 to 4.33. These findings align with Syriopoulou-Delli and Eleni (2022), who reported that AAC tools improve communication and social behavior. Parents and caregivers also expressed higher satisfaction, reflecting the application's positive impact on family relationships, as noted by Demers et al. (2002).

Implications for Future Development

The findings highlight opportunities for advancing the application through artificial intelligence for adaptive symbol selection, multilingual capabilities, and multimedia features. The application's adaptability could extend its use to other populations, such as older adults with neurodegenerative conditions or children with developmental disorders. Collaboration with educational and healthcare institutions could facilitate its adoption, while long-term studies could provide deeper insights into its effectiveness across diverse settings.

Limitations and Recommendations

This study had limitations, including a small sample size (10 Children, 3 Teachers, 1 Speech-Language Pathologist), which limits generalizability. The application's memory usage exceeded benchmarks, potentially affecting performance on resource-constrained devices. Additionally, the short-term evaluation provided limited insights into the application's long-term impact on communication and quality of life.

To address these limitations, it is recommended to expand the sample size to include diverse populations and conduct long-term studies to assess sustained impacts. Practical steps include promoting the application in schools, hospitals, and therapy centers, along with training programs for caregivers and professionals. Future research should integrate advanced features like AI-driven adaptive symbol selection and multilingual support, optimize memory management, and compare the application with other AAC tools to identify areas for enhancement. Evaluating cost-effectiveness will also support broader adoption.

Conclusion

This study underscores the potential of mobile AAC applications to address communication challenges, improve user satisfaction, and promote social inclusion. The findings contribute to the growing body of evidence supporting user-centered and culturally relevant designs in assistive technologies, providing a foundation for future research and development.

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